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MODEL TESTS
FOR THE OPENING-DISCHARGE RATIO
OF A RADIAL GATE

Technical Report No. 1

Contents:

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Summary

For the radial gates of the Welbedacht-Dam in Southafrica, a calibration curve for the relation between gate opening and discharge under constant head condition was established, using a scale model 1 to 50 for one weir. The underflow was found to be stable for all gate openings; some vortex formation in the head water did not disturb the discharge-opening ratio.

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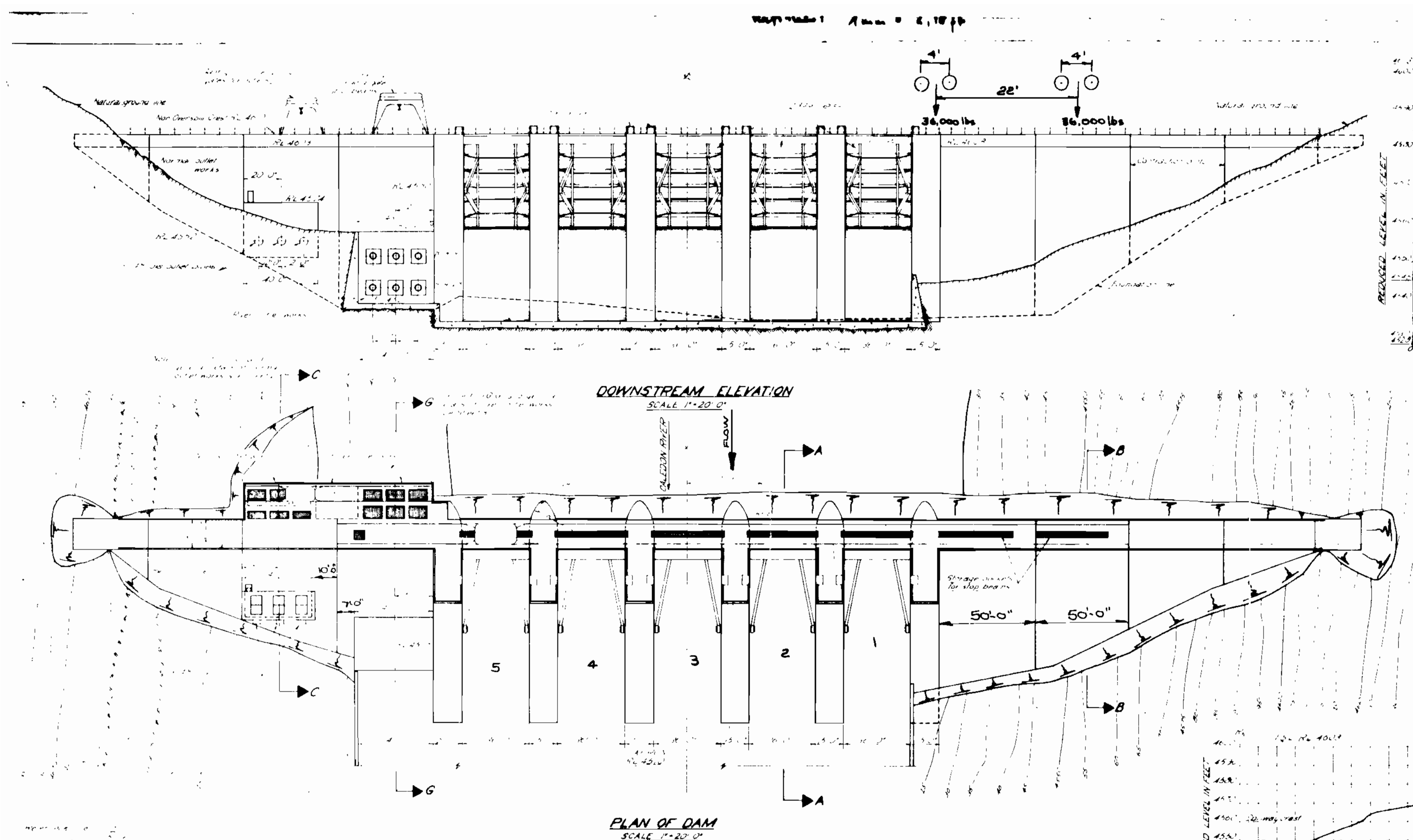
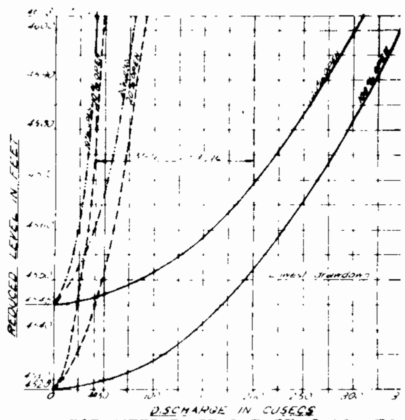
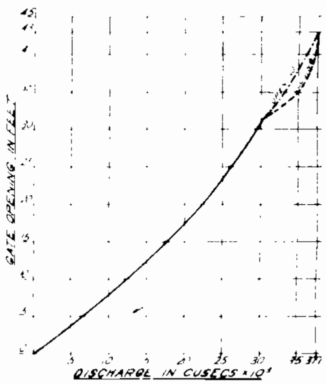


DOWNSTREAM ELEVATION
SCALE 1"=20'0"

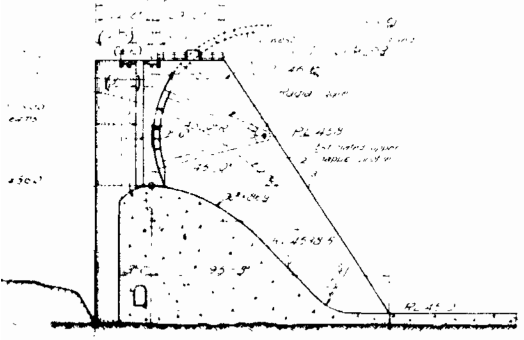
PLAN OF DAM
SCALE 1"=20'0"



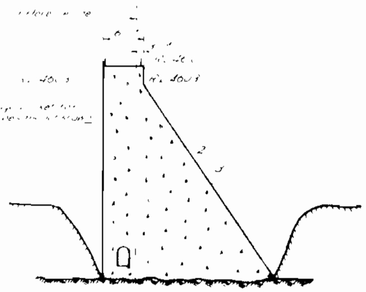
ESTIMATED RIVER OUTLET DISCHARGE



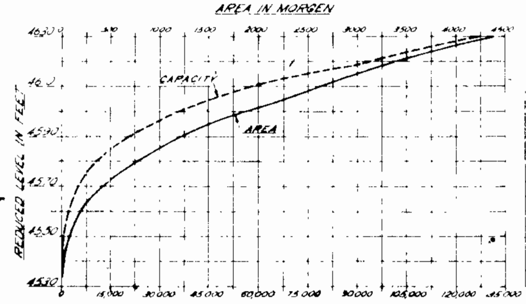
ESTIMATED DISCHARGE RATING C
(WITH RESERVOIR LEVEL AT RL 460.
(DISCHARGE FOR RADIAL GATE)



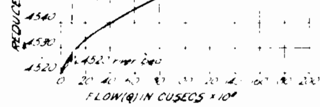
SECTION A-A
SCALE 1"=20'0"



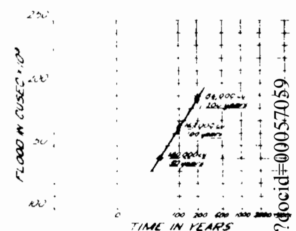
SECTION B-B
SCALE 1"=20'0"



SURFACE AREA AND CAPACITY		
CONTOUR	AREA	CAPACITY
4533	0 00	0 00
4540	21 23	37 03
4550	80 13	496 73
4560	180 27	1748 93
4570	424 47	4642 32
4580	780 05	10,527 83
4590	1211 03	20,362 33
4600	1921 76	35,822 93
4610	2625 45	58,394 93
4620	3397 99	88,381 53
4630	4393 52	127,169 53



TAILWATER RATING CURVE



FLOOD FREQUENCY

REFERENCE DRAWINGS
General Details of Normal Outlet Works Sheet 2/ Reg Nº CRP
General Details of River Outlet Works Sheet 3/ Reg Nº CRP

THIS PLAN SUPERSEDES PLANS REG Nº 49735/c9 & 5049

FIG. 1
PROPOSED DESIGN OF DAM

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1. Introduction

For the Welbedacht-Dam in Southafrica, 5 radial gates shall be used for the control of an irrigation system (Fig. 1). This control has been planned as an automatic system; for the lay-out of the regulation the opening-discharge ratio (calibration curve) must be known.

The steel gates are under construction by the DSD-DILLINGER STAHLBAU GmbH, DILLINGEN, WEST GERMANY. From this contractor, model tests were asked to be carried out by the Technical University of Brunswick in West Germany (TECHNISCHE UNIVERSITÄT BRAUNSCHWEIG).

According to the Tender Document pg. 22 (Model Tests), the investigations shall give following informations:

(a) Determination of the hydraulic data necessary for the design of the gates,

(b) Determination of the safe minimum opening of the gates,

(c) Determination of discharge volumes in m^3/s at partial gate openings defined by the vertical distance of the bottom edge of the skinplate from the concrete crest in intervals of 10 cm at constant reservoir level R.L. 4603' (1402.99 m) (calibration curve), as basis for the discharge recorder.

The investigations were carried out in the hydraulic laboratory of the LEICHTWEISS-INSTITUT at the Technical University of Brunswick.

2. Description of the Model

For the determination of a calibration curve, it is not necessary to reconstruct the complete dam in a model; such a model would become very large and expensive in costs and time. Only one opening therefore was used. It is clear, that some interaction may occur if two neighbour gates are operated with different discharges. Here the flow pattern upstream of the gates is not symmetrical; the influence of the neighbour gates on the calibration curve, however, will be negligible for partial opening.

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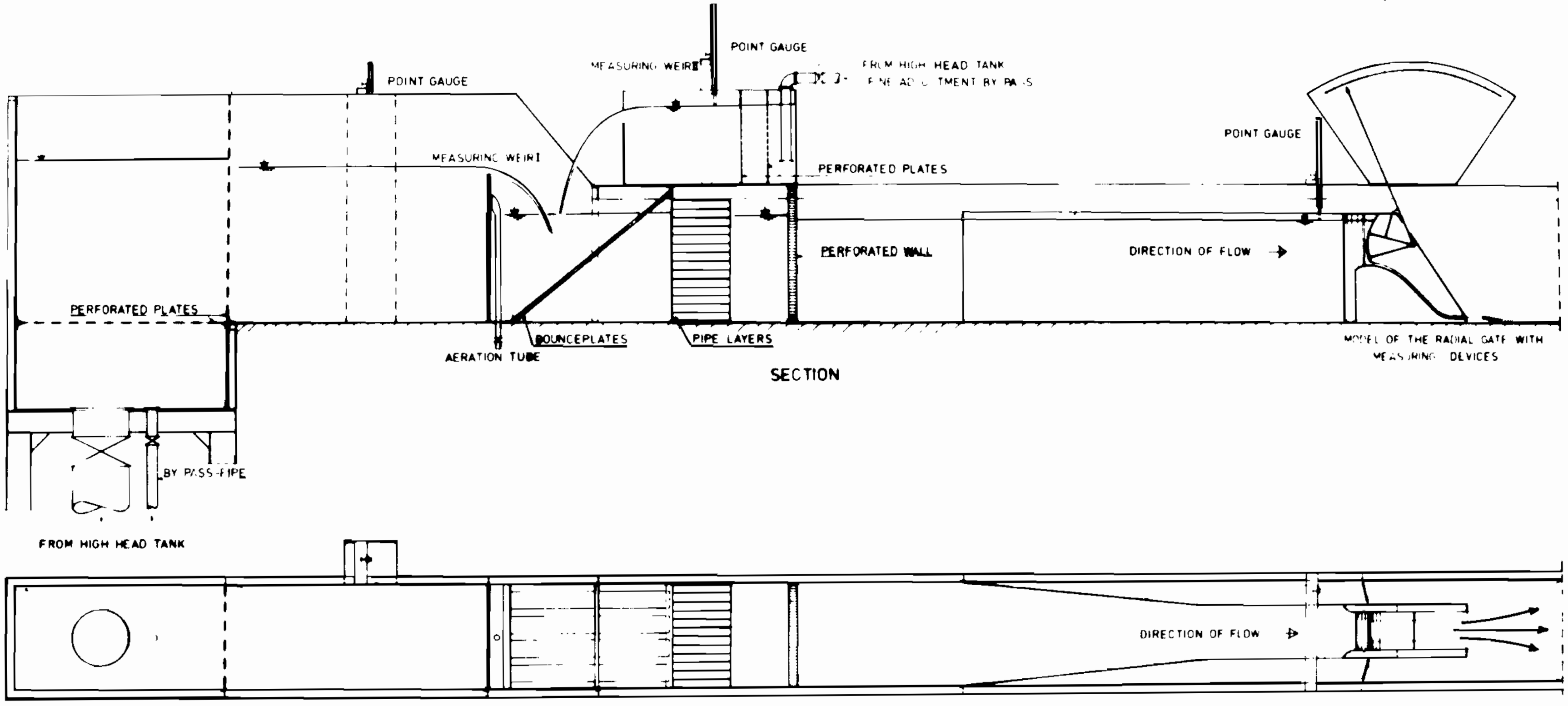

TOP PLAN

FIG 2
MODEL SET UP

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In order to simulate the conditions for one opening, the weir crest, the side walls, and the piers till to their axis had been reproduced in the model as to be seen from Fig. 2. In this manner the contraction of the incoming flow is the same as in the prototype. The model was placed in the hydraulic channel of the LEICHTWEISS-INSTITUT; with respect to the water supply, the model scale was selected to

$$1 : k = 1 : 50.$$

After FROUDE's law, the scales for the parameters of interest are

openings	$1 : k =$	$1 : 50$
discharges	$1 : k^{2.5} =$	$1 : 31250$ 7762.

With a scale of 1 to 50, the accuracy of the measurements is given. Because friction effects are small, REYNOLDS'law can be neglected; for small openings and water depths on the weir crest, some capillary or surface tension effects are possible which are stronger in the model than in the prototype.

Because of the existence of supercritical overflow on the weir, the downstream conditions are not of importance with regard to the discharge.

The model set up and the locations of the measurement devices are shown on Fig. 2. For the discharge measurements, two calibrated measuring weirs were used, weir No. I (rectangular type) for rough, weir No. II (triangular type) for fine adjustment of discharge. For an undisturbed water level in the headwater of the gate, a pipe layer system and a perforated wall are damping the water level undulations from the overfalls of the weirs. The constant reservoir water level was controlled with a point gauge (about $\pm$ 0.1 mm) in the model; for the gate opening measurement a special scale apparatus was constructed from which the gate opening can be read as defined in the Tender Document (Fig. 3).

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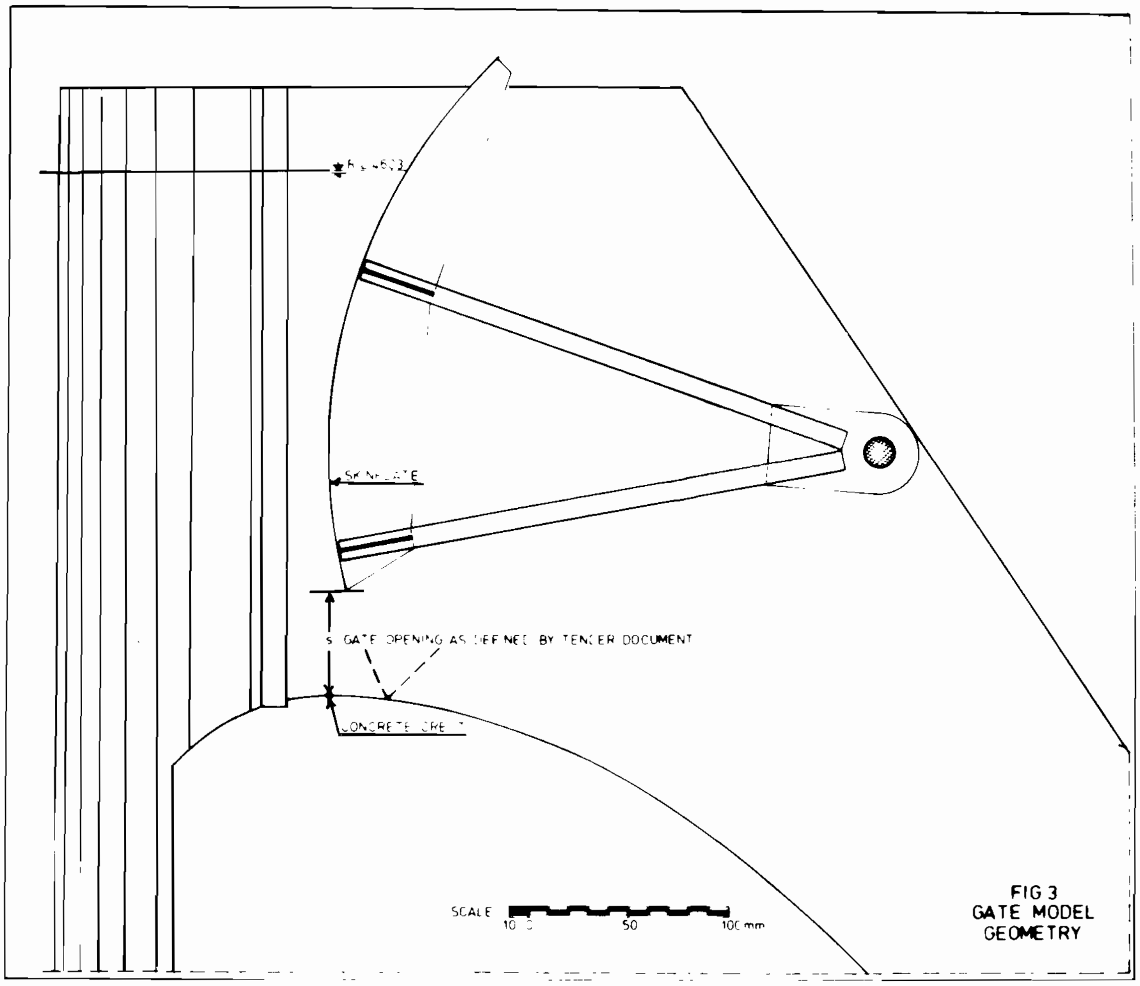

FIG 3
GATE MODEL
GEOMETRY

Fig. 4 gives a picture of the upstream view of the model with its measuring devices, Fig. 5 a downstream view; Fig. 6 shows the outflow under the gate (model under operation).

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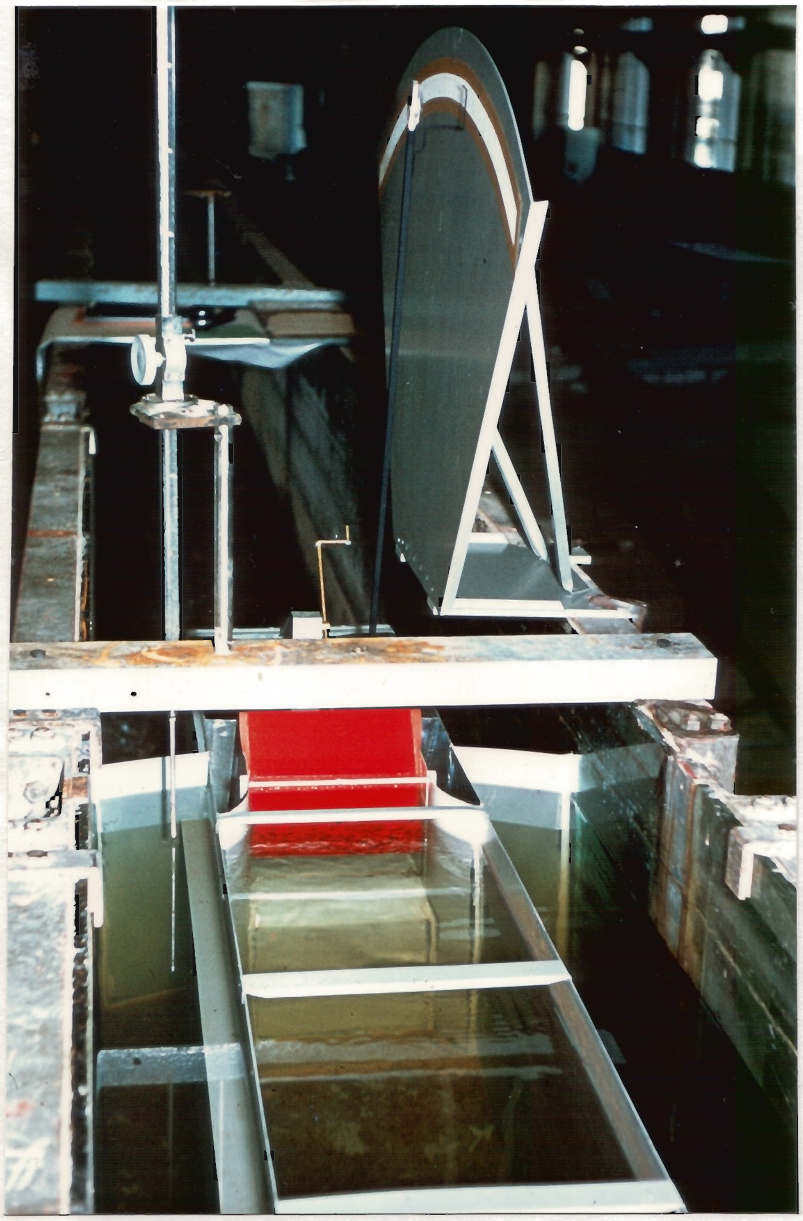
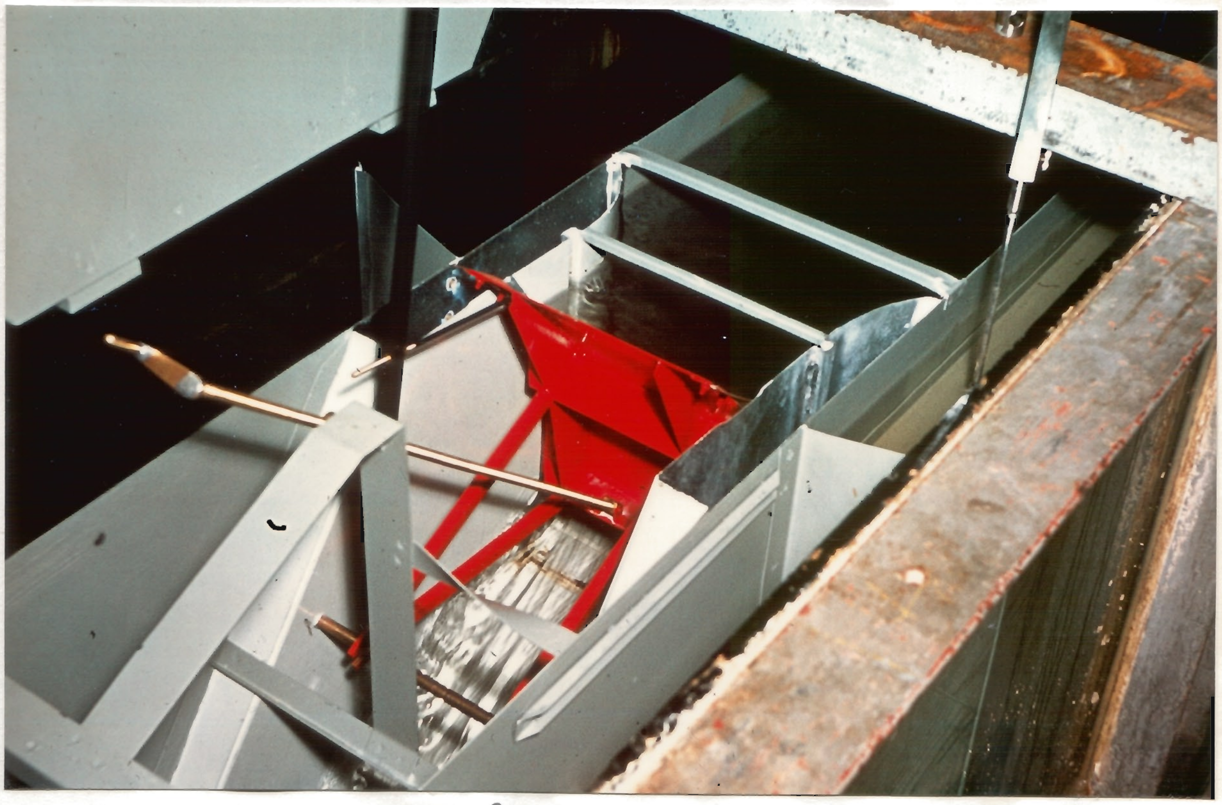


Fig. 4

Upstream View of the Model

Fig. 5

Downstream View of the Model



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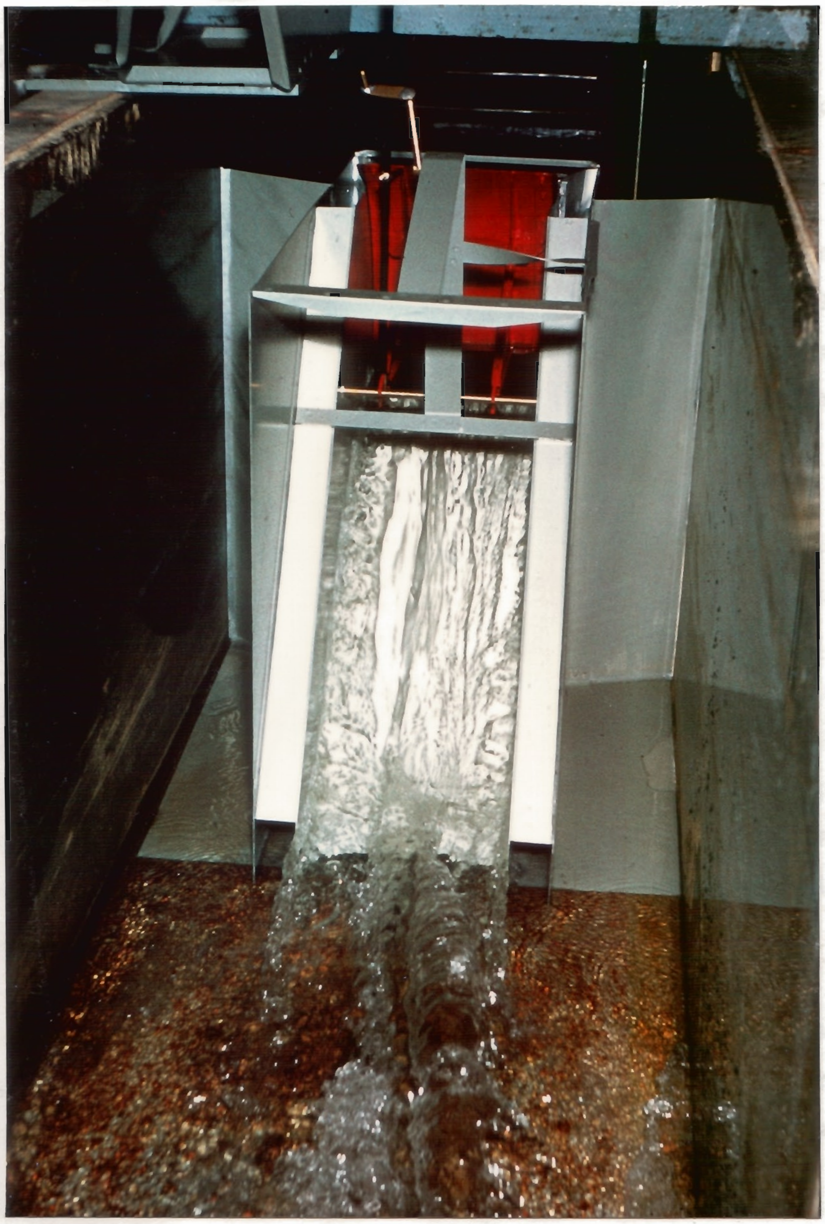

Fig. 6
Model under Operation

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3. Results

The results of the model tests are presented on Fig. 7 and 8; all data are scaled up after FROUDE's Law to the prototype.

For a control of the results, 3 test series were carried out. They are marked by different notations of the measuring points on Fig. 7 and 8. Generally, the opening of the gate s as defined by the Tender Document (s = vertical distance between the weir crest and the skinplate of the gate) was regulated in steps of 10 cm (prototype).

Additionally, the results are given numerically in the tables of the appendix. Fig. 7 gives the calibration curve with the discharges Q from s = 0 till s = 10.2 m for constant head upon 1402.99 m.
For s = 10.2 m, a sudden transition to free overflow regime was observed without any transient range estimated in the curve shown on Fig. 1. This computed curve also is drawn on Fig. 7 and shows a good agreement with the measurments; till s = 6.0 m, the calculated curve shows little higher values; for high opening rates the measured discharges become higher than the attached calculated values.

The scattering of the measurements is considered to be fairly low. Because of the small intervals of calibration, the measuring points with their short distances from one another connect themselves to a curve of calibration (Fig. 7).

A dimensionless presentation of the results shows Fig. 8 where the μ-values are plotted over the opening rate s. The μ-values are evaluated from the measured data after the formula of TORICELLI;

$$Q = \mu \; . \; s \; . \; B \sqrt{2gh}$$

where μ gives the deviation from the theoretical value due to (vertical and horizontal) contraction, curvature of streamlines a.s.o. For s in the order of magnitude of h, the TORICELLI equation is not exact and should

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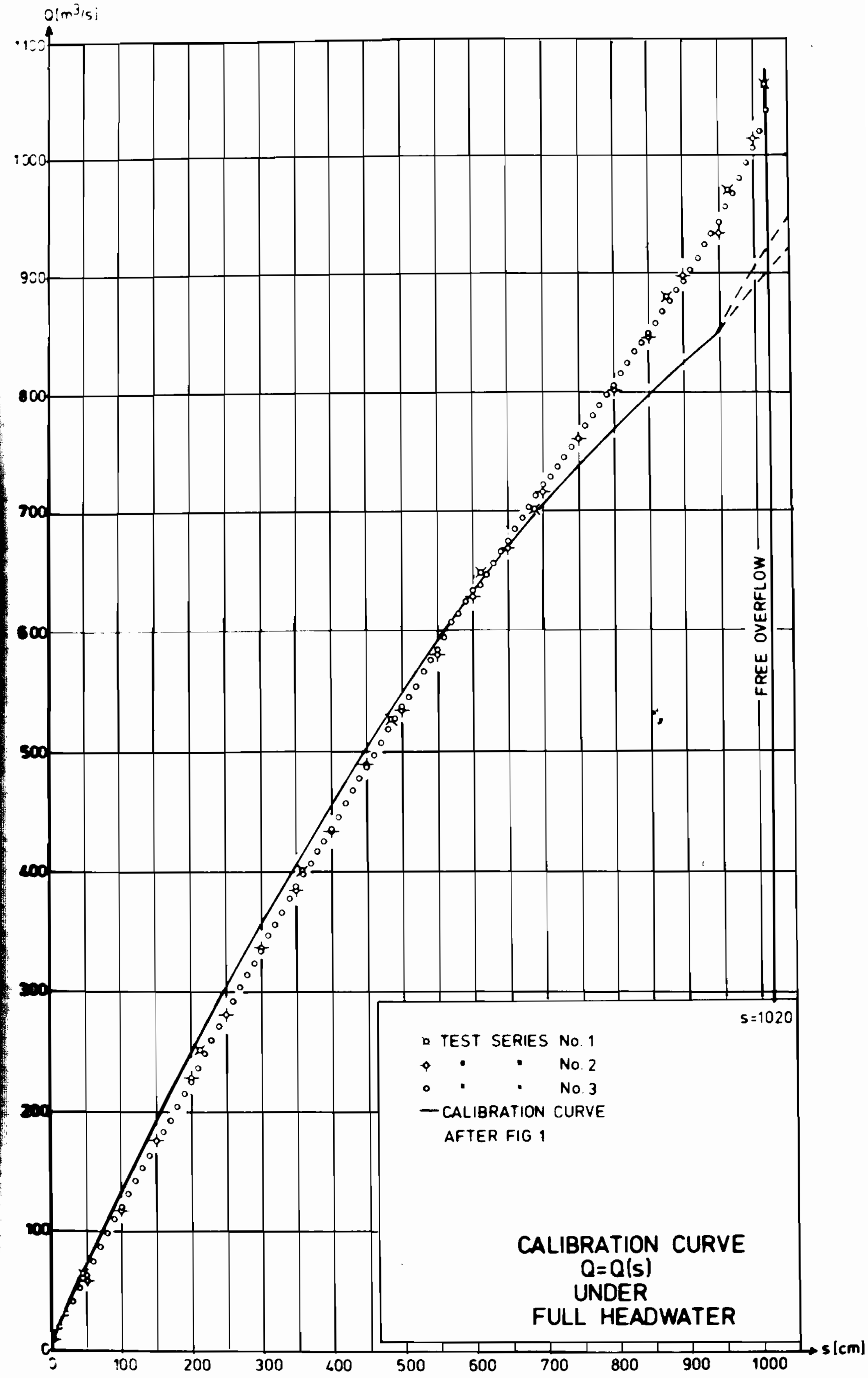

FIG. 7

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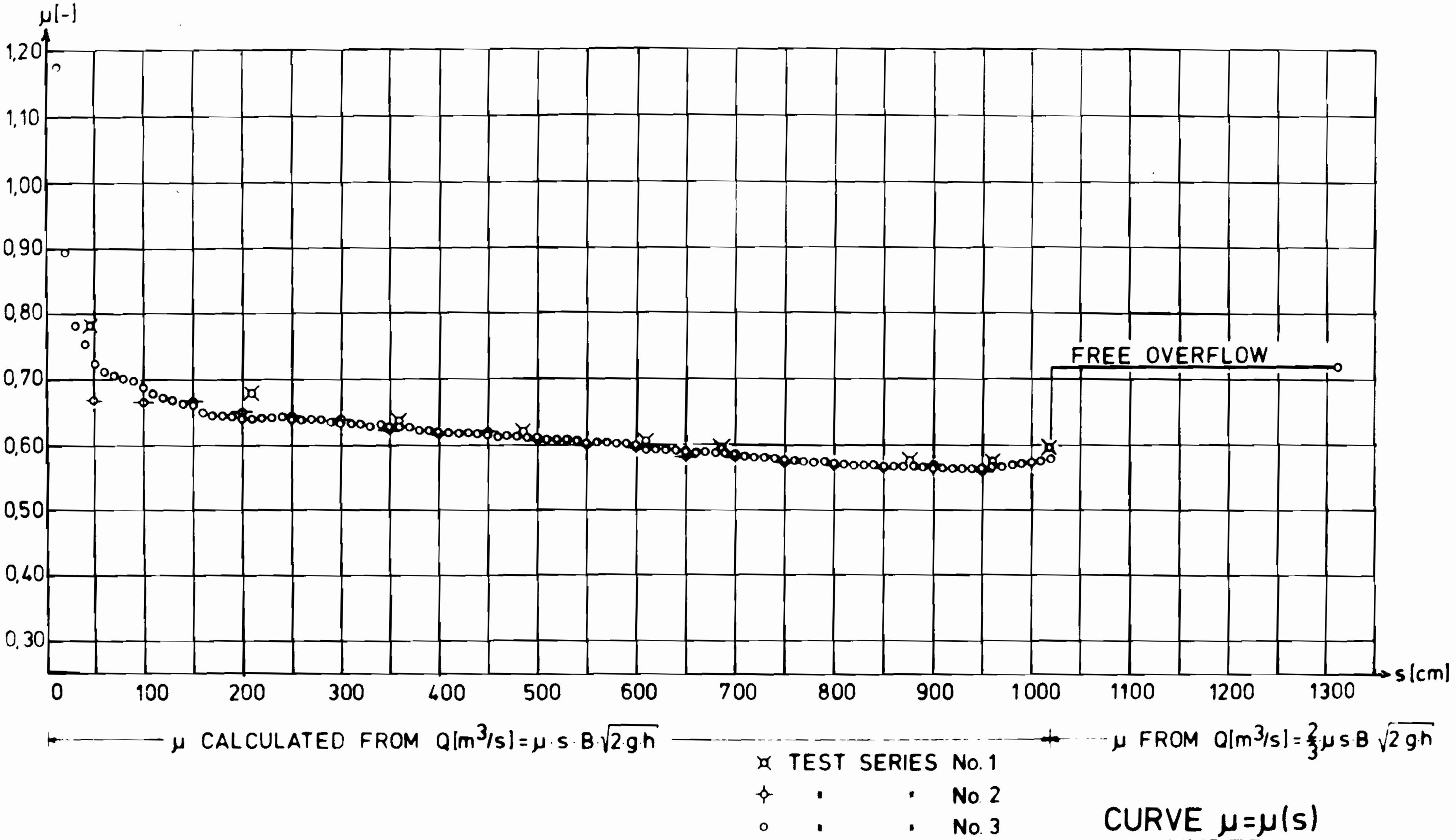

FIG. 8

CURVE $\mu = \mu(s)$
UNDER
FULL HEADWATER

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be substituted by an integral expression; for comparison of the results, however, the μ-value after TORICELLI can be used for the complete range of s till s = 10.2 m. Here the regime of free overflow is beginning with a constant value of μ for the constant head of 1402.99 m; this μ-value is computed from the formula for free overflow

$$Q = \frac{2}{3}\ \mu\ .\ s\ .\ b\sqrt{2gh}$$

and gives a number of .72 in good agreement with experience from other investigations.

For gate openings from s = .5 m till 10.2 m, the μ-values are decreasing from .72 till about .56. This can be explained by the increasing ratio opening-head which gives the difference to the assumptions leading to the equation of TORICELLI.

For smaller openings than s = .5 m, very high values for μ occur. This is due to the fact that the opening rate after the definition of the Tender Document is not exactly the effective opening distance which is the shortest distance between gate and weir. This difference becomes important for small gate openings only. In this range a certain scattering of results can be observed due to the small discharges and the connected influence of measuring errors. In the mean range of the curve, the scattering is very low similar to Fig. 7.

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4. Special Observations

For all opening rates, a stable underflow beyond the gate was observed. Even for small opening rates about s = .2 m, the flow was fixed on the weir crest and there was no different behaviour of flow as that of higher opening rates. It shall be mentioned here that aeration effects of the supercritical flow cannot be reproduced by a scale model; these effects, however, are without influence on the discharge.

As already mentioned above, also till to the free overflow condition a stable pattern of the underflow was found out. It was without influence whether the gate was lowered or heaved; in all cases for an opening rate of s = 10.2 m the regime of free overflow was ending or beginning (Fig. 7 and 8). This may be explained by the fact that the skinplate of the gate is touching the overflow level nearly perpendicularily.

In the headwater of the gate, a special observation was made concerning vortex action. Upstream to the well known separation zone directly in front of the skinplate of the gate, for higher gate openings a mostly double vortex formation was noted, with the vortex axis near to the slots of the stop logs (Fig. 9 and 10). This vortex action is beginning at opening rates of about s = 2 m and increases till s = 5 m; in this range the vortex action can be determined as soft because the vortex formation is unstable and weak, only for short times an air vortex reaches the tailwater. In the range between s = 5 m and s = 7 m, however, a strong vortex action can be reported in the manner, that the vortices become more stable and air tubes grow for longer durations till to the tailwater surface. For higher gate openings up to s = 9.5 m, the vortex activity decreases to soft action; this is due probably to the increasing disturbances in the head water level by the undulations from the separation zone.

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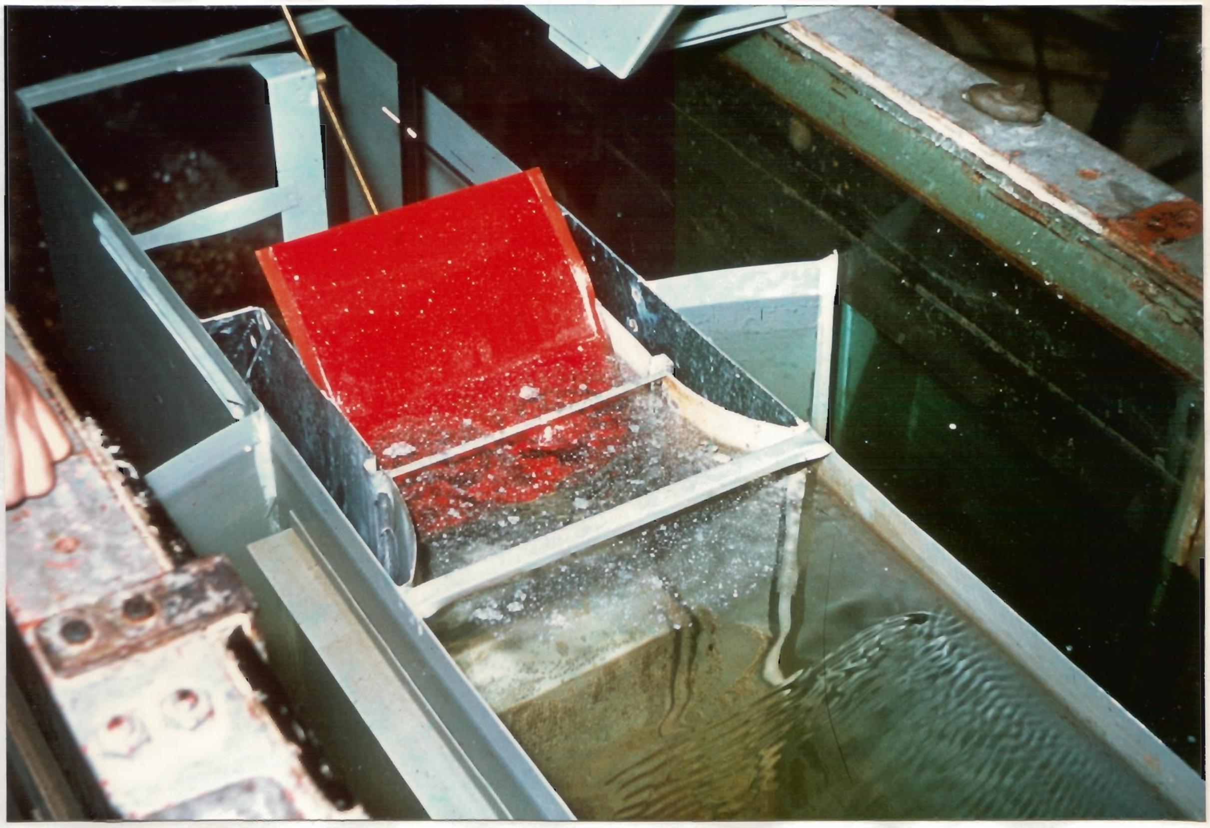

Fig. 9

Vortex Action

Slots for the Stoplogs Open

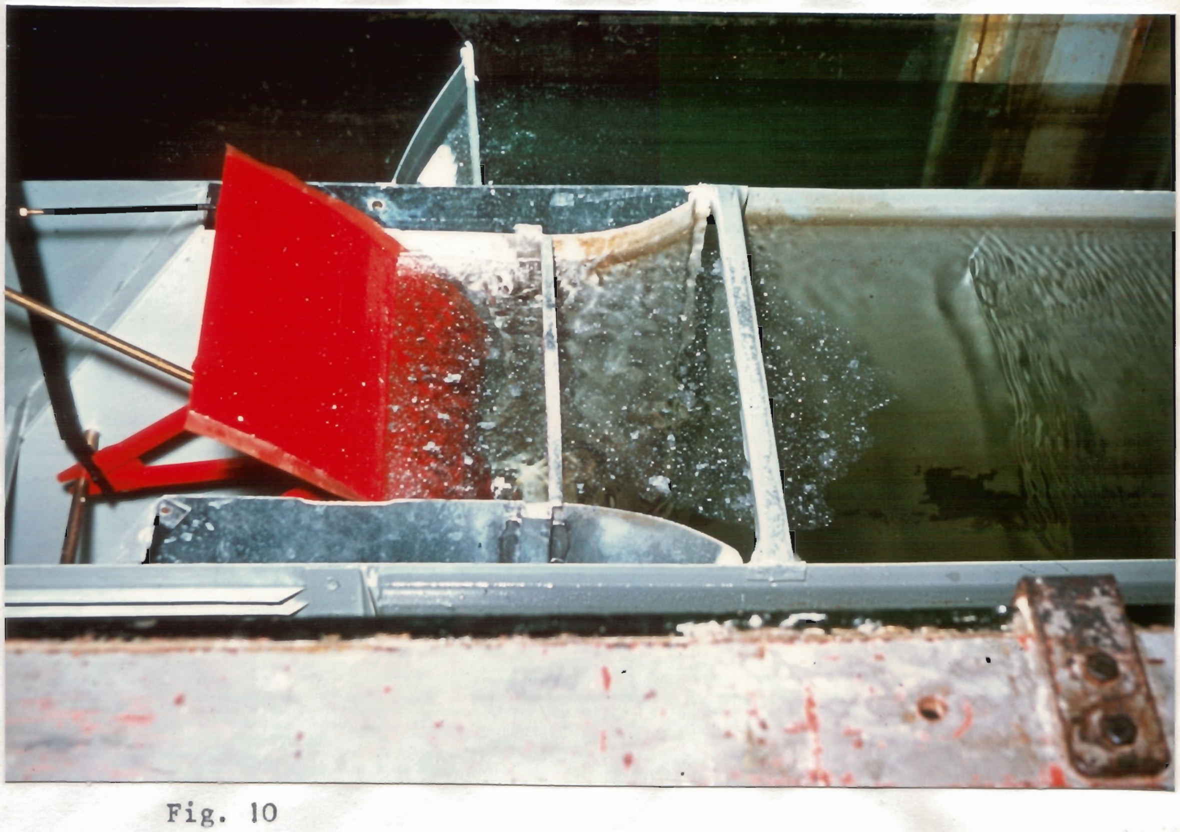

Fig. 10

Vortex Action

Slots for the Stoplogs Closed

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It could be supposed that the slot openings for the stoplogs at the side walls have an influence on the creation or location of the vortices. By closing the slots, however, no remarkable difference of vortex activity was to be seen. It seems that the geometry of the pier head is the most important reason for it, by retardation of the inflow at the side walls.

For the discharge-opening ratio, however, in the model no measurable influence could be stated. This can be seen also from the low scattering in Fig. 7 and 8. In the prototype, the probability of stable vortex formation will be lower due to the higher disturbances by turbulence and water level undulations.

Führböter

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A. Führböter

Büsching

wiss.Assistent Dipl.-Ing.
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http://ww ... de/?docid=00057059 14/07/2014

5. Appendix:

erical Results of the Test Series.

tations:

all tables means

1. s [cm] — the gate opening defined after the Tender Document

2. Q [m^3/s] — the discharge under constant head of 1402.99 m

3. μ [-] — the dimensionless number evaluated after the equation from TORICELLI
$Q = \mu \cdot s \cdot B \cdot \sqrt{2gh}$

x — behind μ: soft vortex action
xx — behind μ: strong vortex action

NUMERICAL RESULTS OF THE TEST SERIES No. 1

1	2	3
s [cm]	Q [m^3/s]	μ [-]
47.50	65	0.782
211.25	252	0.678 x
358.75	401	0.636 x
486.25	528	0.617 xx
610.00	649	0.604 xx
686.75	702	0.596 xx
875.00	880	0.572 x
961.25	971	0.574
1016.25	1062	0.594

http://www -bs.de/?docid=00057059 14/07/2014

NUMERICAL RESULTS OF THE TEST SERIES No. 2

1	2	3
s [cm]	Q [m^3/s]	μ [-]
0	10	-
50	59	0.669
100	117	0.665
150	176	0.666
200	229	0.650 x
250	281	0.639 x
300	337	0.638 x
350	385	0.624 x
400	435	0.618 x
450	489	0.617 x
500	534	0.607 xx
550	580	0.599 xx
600	629	0.595 xx
650	669	0.580 xx
700	716	0.581 xx
750	761	0.576 x
800	804	0.571 x
850	845	0.565 x
900	898	0.567 x
950	933	0.558 x
1000	1013	0.576

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NUMERICAL RESULTS OF THE TEST SERIES No. 3

1	2	3	1	2	3
s [cm]	Q [m^3/s]	μ [-]	s [cm]	Q [m^3/s]	μ [-]
0	10		310	347	0.633 x
10	20	1.155	320	356	0.632 x
20	31	0.894	330	366	0.629 x
30	42	0.787	340	378	0.631 x
40	53	0.753	350	388	0.629 x
50	64	0.723	360	398	0.628 x
60	75	0.711	370	407	0.626 x
70	87	0.706	380	416	0.622 x
80	99	0.701	390	426	0.621 x
90	110	0.697	400	436	0.619 x
100	121	0.688	410	446	0.617 x
110	132	0.679	420	457	0.617 x
120	142	0.673	430	467	0.618 x
130	153	0.668	440	478	0.616 x
140	164	0.663	450	487	0.615 x
150	174	0.661	460	497	0.613 x
160	183	0.650	470	507	0.614 x
170	193	0.645	480	518	0.613 x
180	205	0.645	490	527	0.612 x
190	215	0.643	500	537	0.611 xx
200	226	0.641 x	510	545	0.608 xx
210	236	0.639 x	520	554	0.606 xx
220	248	0.641 x	530	566	0.606 xx
230	260	0.641 x	540	575	0.606 xx
240	272	0.642 x	550	584	0.604 xx
250	281	0.639 x	560	594	0.604 xx
260	292	0.638 x	570	606	0.604 xx
270	304	0.638 x	580	614	0.602 xx
280	314	0.637 x	590	624	0.602 xx
290	324	0.634 x	600	633	0.601 xx
300	334	0.633 x	610	637	0.594 xx

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1	2	3
s [cm]	Q $[m^3/s]$	μ [-]
620	646	0.593 xx
630	656	0.592 xx
640	665	0.592 xx
650	674	0.589 xx
660	684	0.589 xx
670	694	0.589 xx
680	703	0.587 xx
690	712	0.586 xx
700	722	0.586 xx
710	728	0.583 x
720	736	0.581 x
730	745	0.580 x
740	753	0.578 x
750	762	0.577 x
760	771	0.576 x
770	780	0.575 x
780	788	0.574 x
790	798	0.574 x
800	806	0.573 x
810	815	0.572 x
820	823	0.570 x
830	833	0.570 x
840	841	0.569 x
850	849	0.567 x
860	858	0.567 x
870	866	0.566 x
880	876	0.566 x
890	885	0.565 x
900	893	0.564 x
910	902	0.563 x
920	911	0.563 x
930	923	0.564 x
940	933	0.564 x
950	942	0.564 x
960	956	0.566
970	967	0.566
980	979	0.568
990	993	0.570
1000	1005	0.571
1010	1020	0.574
1020	1039	0.579

FREE DISCHARGE Q $[m^3/s]$	μ calculated from $Q=\frac{2}{3}\,\mu.s.B.\sqrt{2.g.h}$
1105	0.718

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